Lowering Mission Cost by Changing Space Engineering Practice

Martin Elvis, Harvard-Smithsonian Center for Astrophysics.

It is a priority for space astrophysics to make a systems engineering study of space engineering practices that will become applicable if launch costs to LEO decrease by substantial factors. By substituting mass for complexity ("brawn for brains") it may be possible to halve spacecraft costs, or more, enabling a series of "Greater Observatories" during the studied time period.

With individual flagship missions in both astrophysics and planetary science each exceeding $1 billion, sometimes by a large factor, very few such missions can be approved and launched. Both the Astrophysics and Planetary Decadal reviews were able to recommend only one flagship mission each. Yet the science demands that we increase our ambitions. In astrophysics, the objects we study do not conveniently radiate in just one technologically accessible band, but spread themselves across the electromagnetic spectrum. NASA's current "Great Observatories" program has three missions simultaneously in operation (Chandra, Hubble and Spitzer) enabling a rapid, creative, feedback between X-ray, optical and infrared observations. This synergy will cease soon, as only the James Webb Space Telescope is set to replace the aging Great Observatories. The next flagship X-ray mission, for example, cannot fly before JWST is expected to have ceased operations. In the Solar System, there are many enticing destinations: Europa, Titan, near-Earth asteroids and, of course, Mars. If we can only proceed in series, it will be a generation before we can visit them all.

If mission costs could be cut by a factor 2 this would enable the pace of astrophysics and planetary missions to be doubled, radically altering the scene. Larger cost savings would be even more transformative.

Launch costs comprise 25%-50% of total mission costs. Naively then, zero launch cost would make for a useful but not dramatic difference. Yet the cost penalty for increased mass ripples through the design decisions throughout a mission. The high cost/kg to LEO has held quite constant (in inflated adjusted dollars) for several decades. As a result, space engineering practice has become finely tuned to minimizing mass.

The study should examine a regime in which mass is less of the driver in mission design. Can mass be traded for complexity and design- and testing-hours? We hope to help systems engineers make more effective design decisions, should lower launch costs become a reality.

Launch costs have long stood as a significant barrier to potential space missions, making launch mass a significant cost factor in concept development. The advent of SpaceX's Falcon 9 Heavy promises to lower the specific launch costs an order of magnitude and at the same time greatly increases the launch mass capability beyond what is currently available through present commercial launch vehicles.

But this positive direction in launch vehicle cost and capacity is likely to be made meaningless by the limits on NASA future mission budgets and the reality of current spacecraft costs. At today's costs, "filling the faring" of one of these high capacity launch vehicles, would represent a major portion of NASA's science budget, and would limit both the number of large missions and other future science projects, as much of the Agency's budget would need to be directed to a single mission.

To truly exploit the opportunity presented by these new launch vehicles, we must rethink the way spacecraft and space missions are designed with a focus on lowering spacecraft costs but accepting greater flight system mass.

Exploring the possibile mission savings and understanding the design trades presented by using mass to enable the use of low-cost technologies not originally intended for space. By bringing together experts in launch vehicles, mission design, and systems engineering with key technologists and space concept scientists, we will be able to look at the major cost advantages that can be achieved with this non-mass limited design. We will be able to see which types of missions are likely to benefit for this new approach and which will not.

Low launch costs to LEO may enable significant mission cost reductions to occur, if the larger mass-to-orbit that becomes affordable is put into making spacecraft and payloads cheaper, rather than simply bigger.

Key Technical Questions/Issues:

While an overall systems approach is essential, we can identify specific technical questions for major sub-systems that require answers:

1. *Power*: Would it make sense to fly much larger solar panels? A metric ton of solar panels could yield 200kW by the end of this decade. With that kind of power, standard commercial equipment (110V/60Hz) could lead to dramatic reductions in component costs. With sufficient mass available, the highest rated kW/kg solar panels need not be used, allowing lower cost commercial products to be used.
2. *Electronics:* Would it make sense to use commercial electronics and protect them with heavy shielding against radiation, rather than building expensive, custom made, radiation-hard devices? Would it make sense to provide atmospheric pressure for commercial electronic components? Can all cabling be shielded against stray noise pick-up, allowing simpler routing?
3. *Reliability:* Would it make sense to achieve systems reliability with multiple, redundant systems, rather than through extremely rigorous, and expensive, standards and testing? Rather than designing systems with "Side A/Side B" electronics, would it be cost effective to use "Side A/ ... /Side J" using e.g. common network reliability standards?
4. *Mechanical Strength*: Would it make sense to build spacecrafts that are rugged—and relatively heavy—rather than always selecting, and paying for, the strongest materials per unit weight? Could less carefully engineered materials provide more cost effective solutions? Could we leverage non-space mass produced structural elements for spacecraft designs?
5. *Testing:* Could mass be used to greatly improve other design margins (e.g., power, downlink data rates) and would it be possible to reduce the testing requirements, given the high margin design.

6. *Design:* From a more general perspective, are engineer-hours spent on design and review a major component of cost? Can mass, then, be used to cut these engineer-hours by creating large design margins for critical parameters?

If the cumulative gains from these new systems engineering choices could reduce mission costs by a factor of 2, this would change the outlook for all space activities.

Timeliness: has announced that their *Falcon Heavy* will be able to deliver 53 metric tonnes to a 200 km LEO (28.5 degree inclination), for $80M to $125M (http://www.spacex.com/falcon_heavy.php). The *Falcon Heavy* is advertised as being available by about 2015. If successful, this will mean launch costs to LEO of between $1500/kg and $2500/kg, only three years from now. This would be a factor of 5 to 10 below current launch costs to LEO.